Evaluation of NCEP GFS clouds using observations & Findings of aerosol climate effects

Zhanqing Li, Hyelim Yoo

Department of Atmospheric and Oceanic Science,
University of Maryland

May 1, 2012

Acknowledgements

Special thanks to our future neighbors

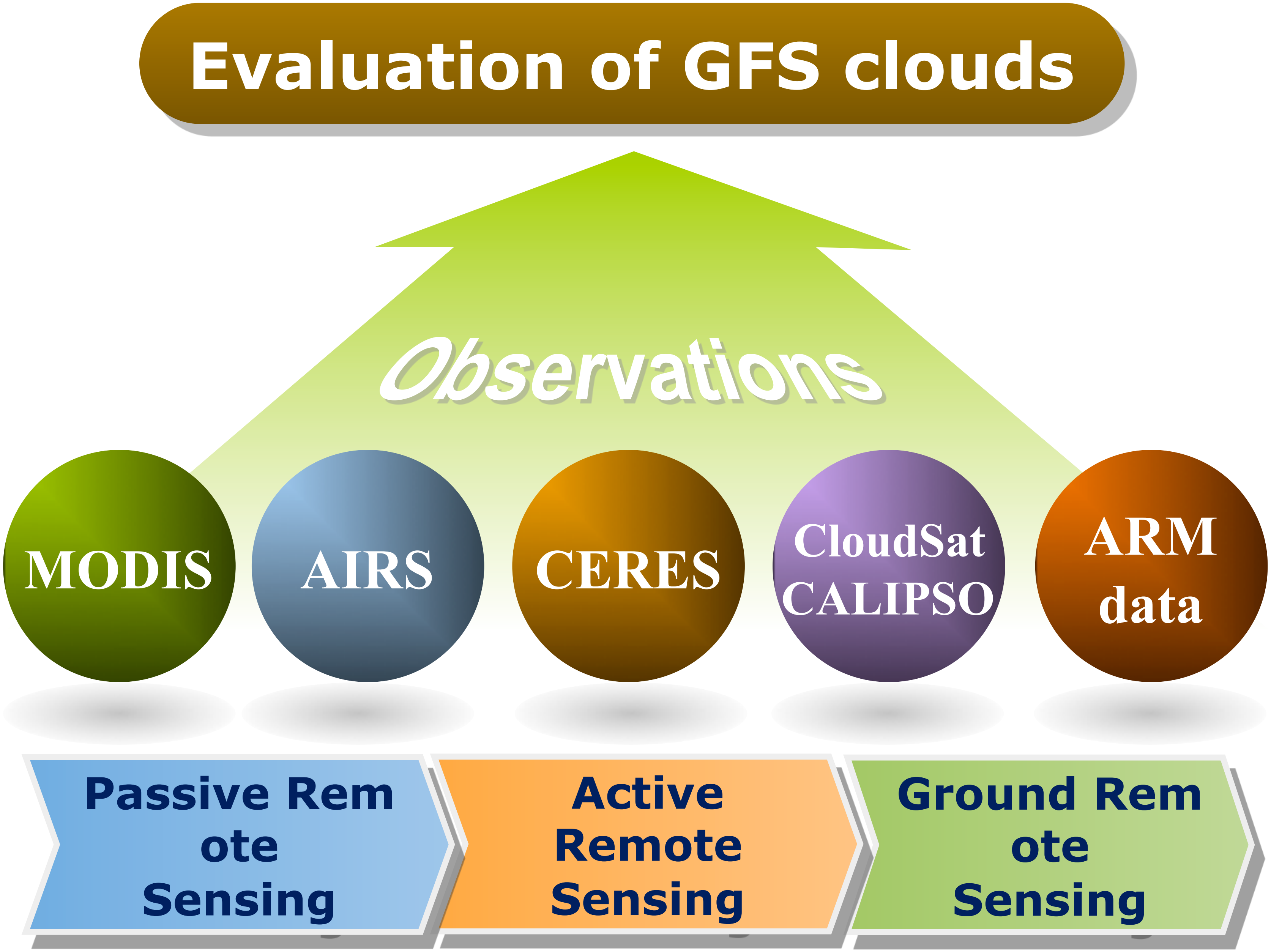
NOAA/NCEP

Drs. Yu-Tai Hou,
Shrinivas Moorthi,
Brad Ferrier, Steve Lord

Overview of the talk

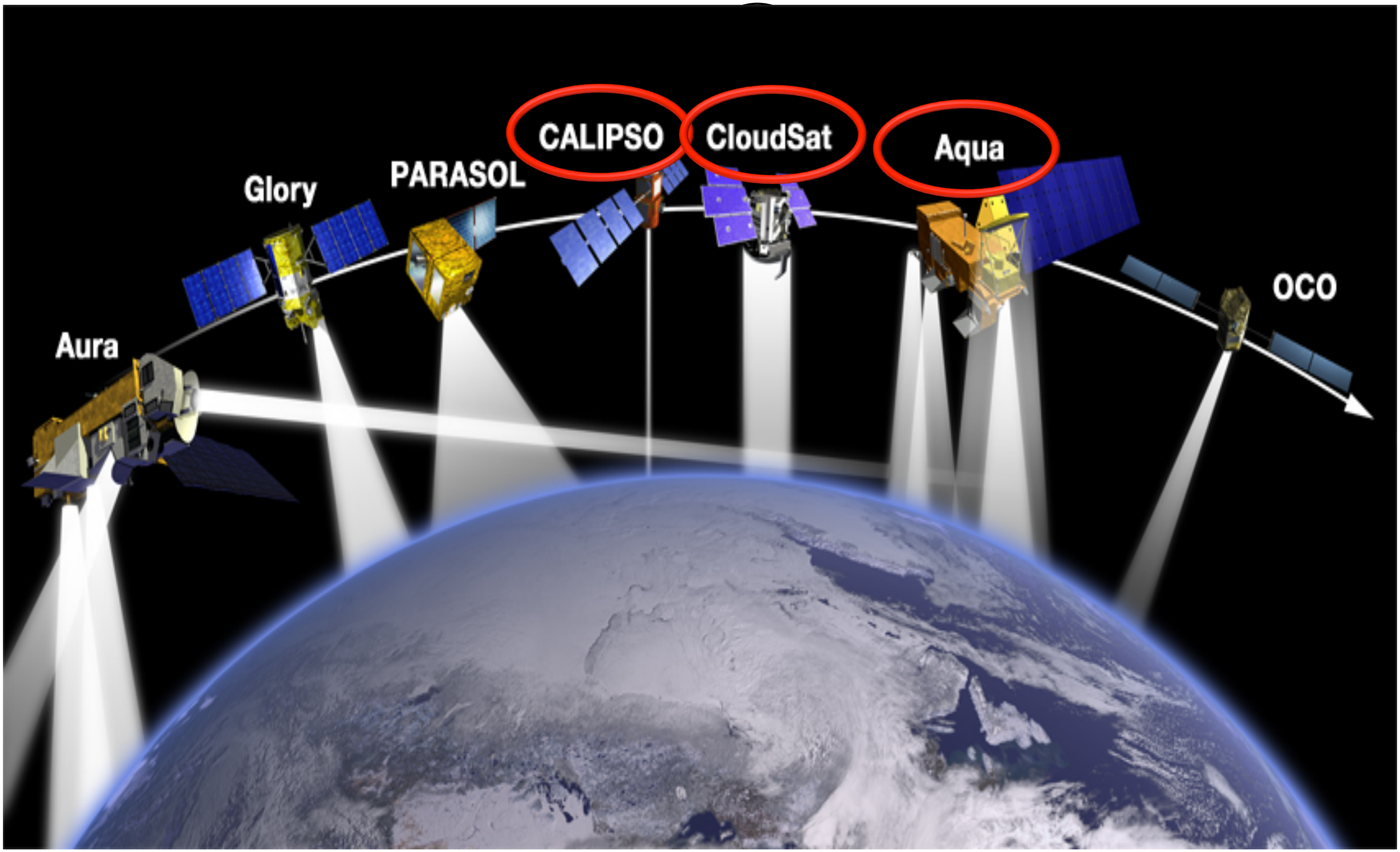
1	Diagnosis	● Diagnosis of the state of GFS model parameterization of cloud variables such as cloud fraction, cloud optical depth, liquid & ice water path
2	Analysis	● Assessment of atmospheric meteorological variables (e.g. RH, T) leading to cloud formation in the GFS model against observational data
3	Application	● Testing of Cloud fraction Scheme & Cloud Overlap Scheme ● Findings of aerosol climate effects and implications for weather & climate modeling

Data & approach



Data & approach

Satellites

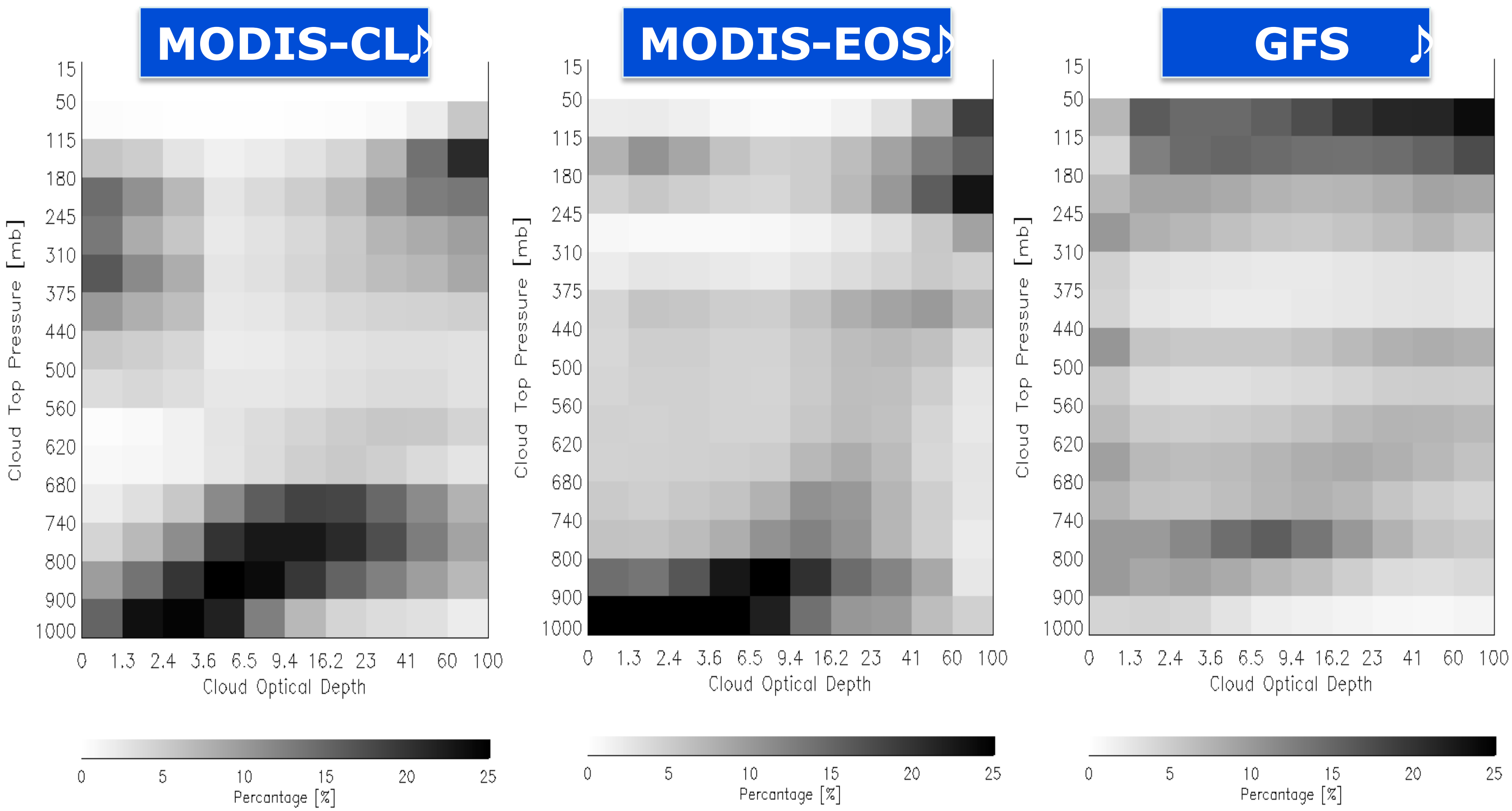


from NASA site♪

Diagnosis of clouds

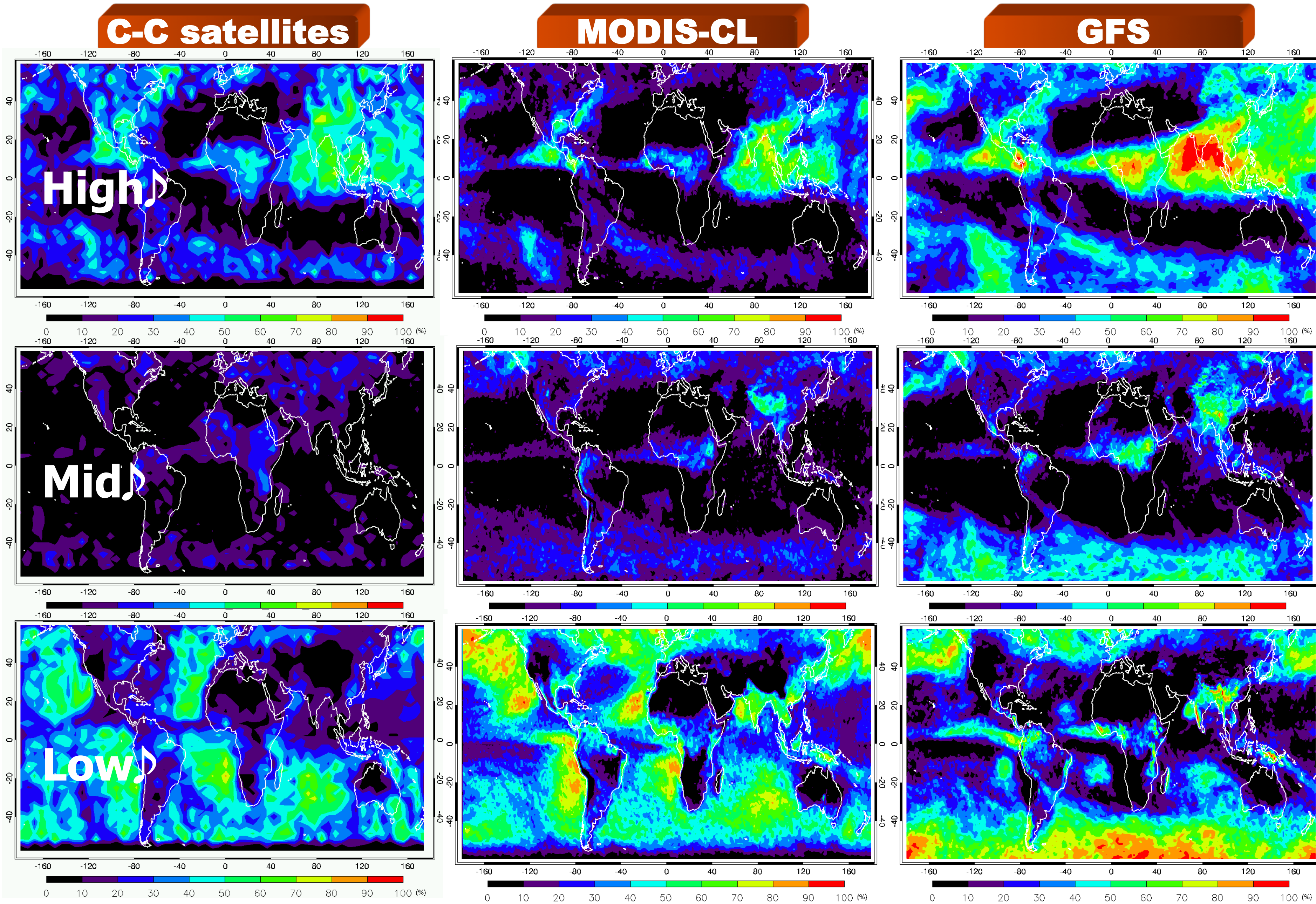
Diagnosis

Cloud top pressure and cloud optical depth

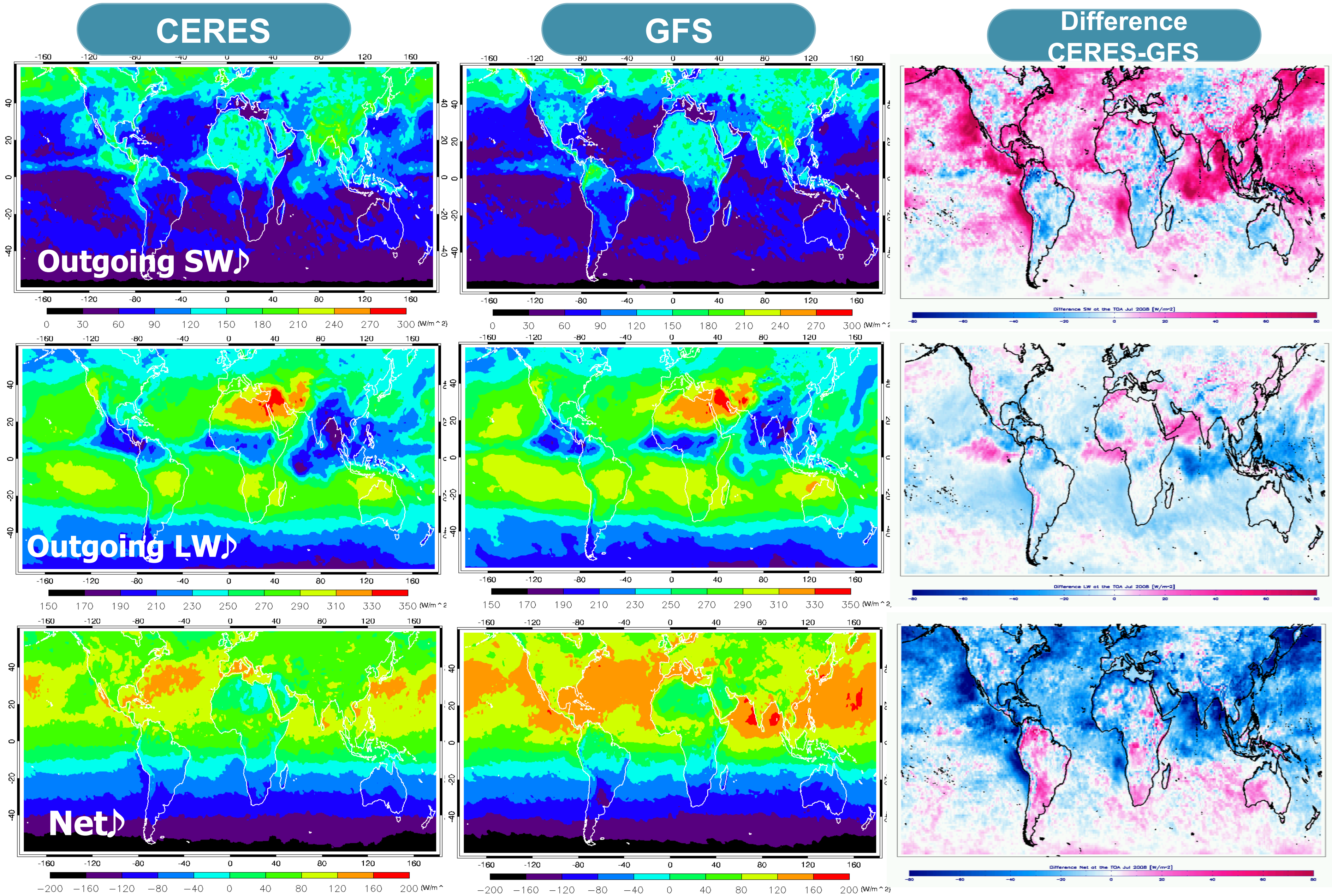


Joint histograms of CTP and COD derived from retrievals by applying the C-L algorithm (left), the MODIS-EOS products (middle), and the GFS model (right) in July 2007.

Comparison Cloud Fraction - July

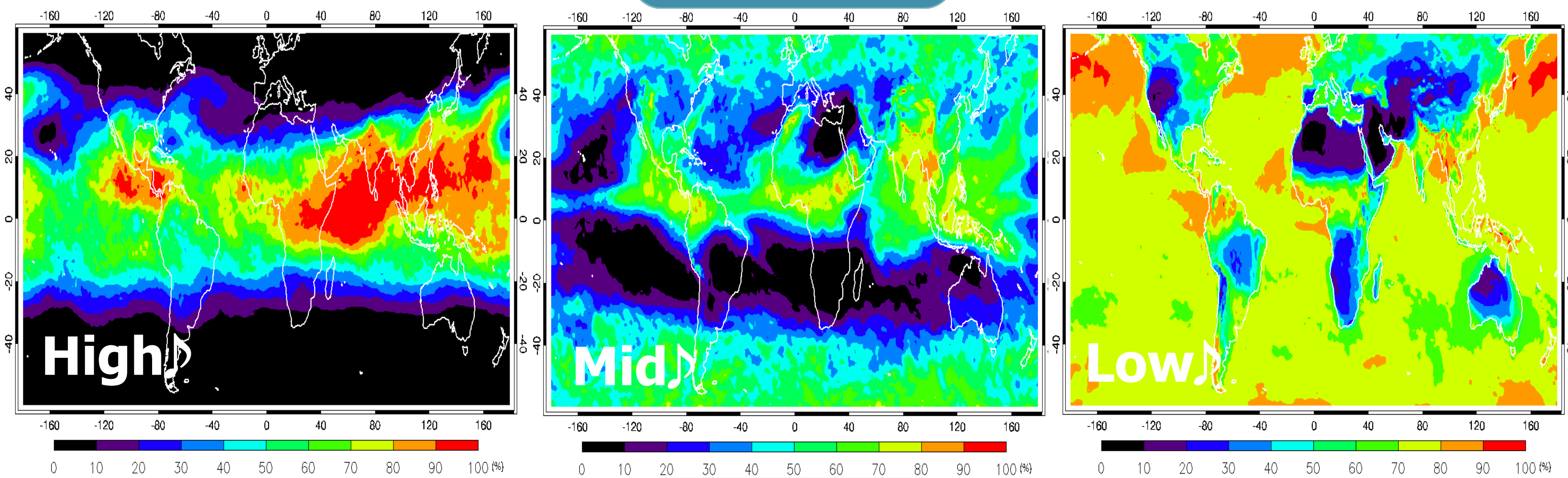


Comparison of radiation at the TOA

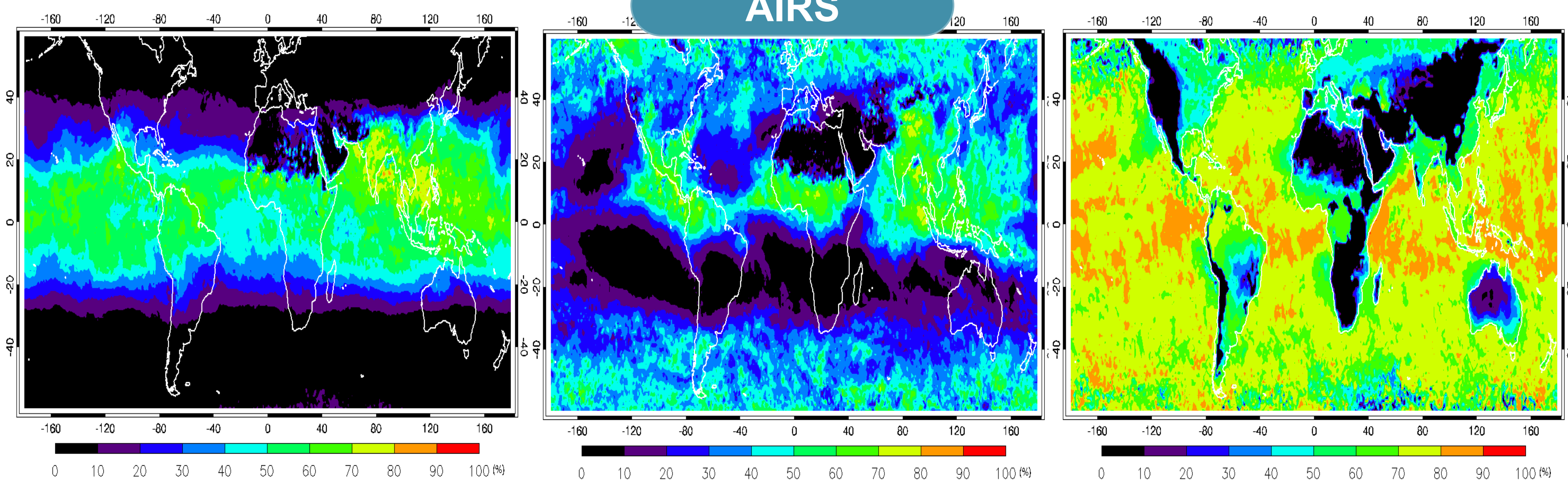


Comparison of RH Fields

GFS

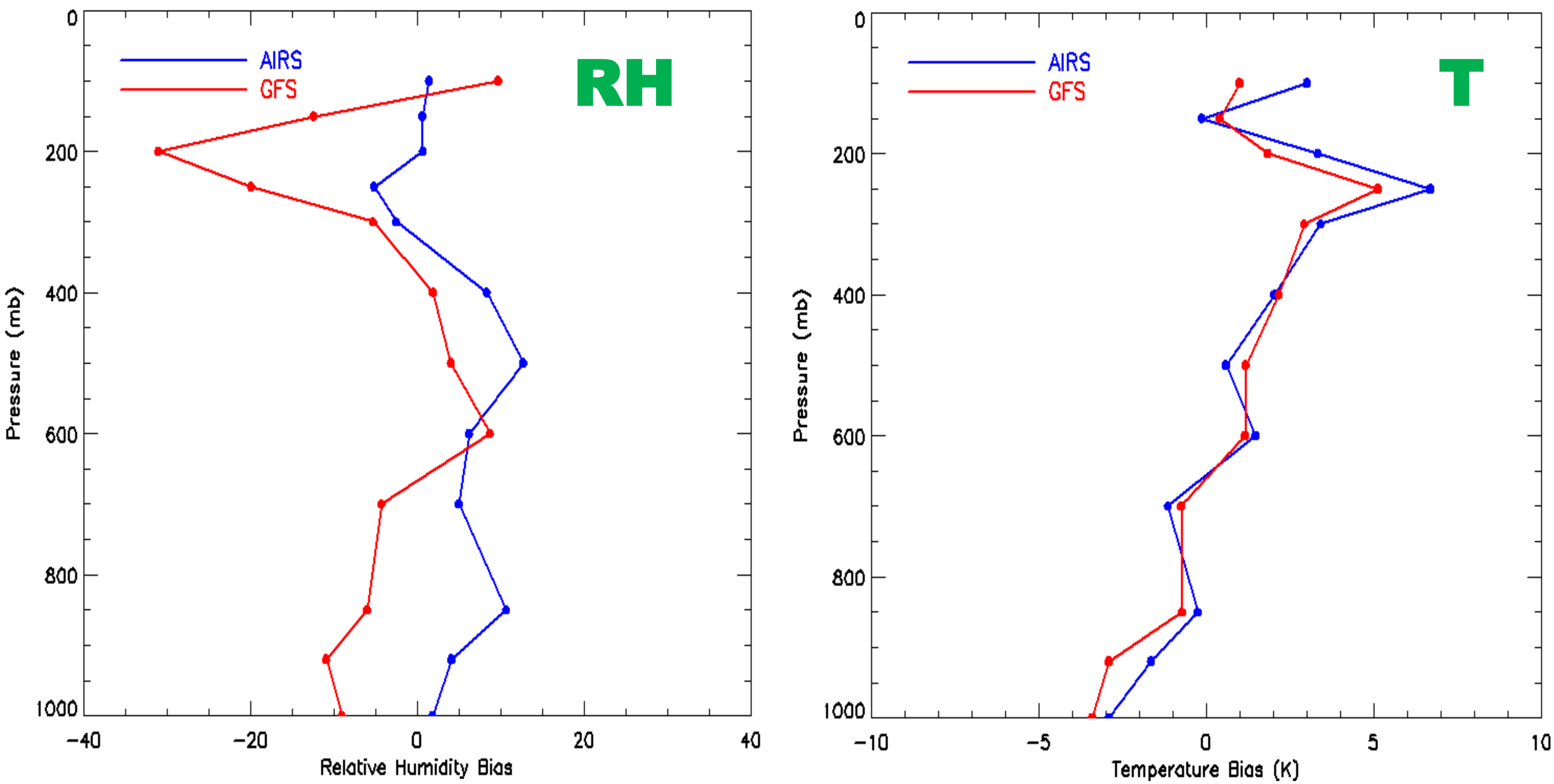


AIRS



Analysis

ARM data at SGP site



Relative humidity (left panel) and temperature (right panel) biases during July 2008: AERI versus AIRS, blue line; AERI versus GFS, red line.

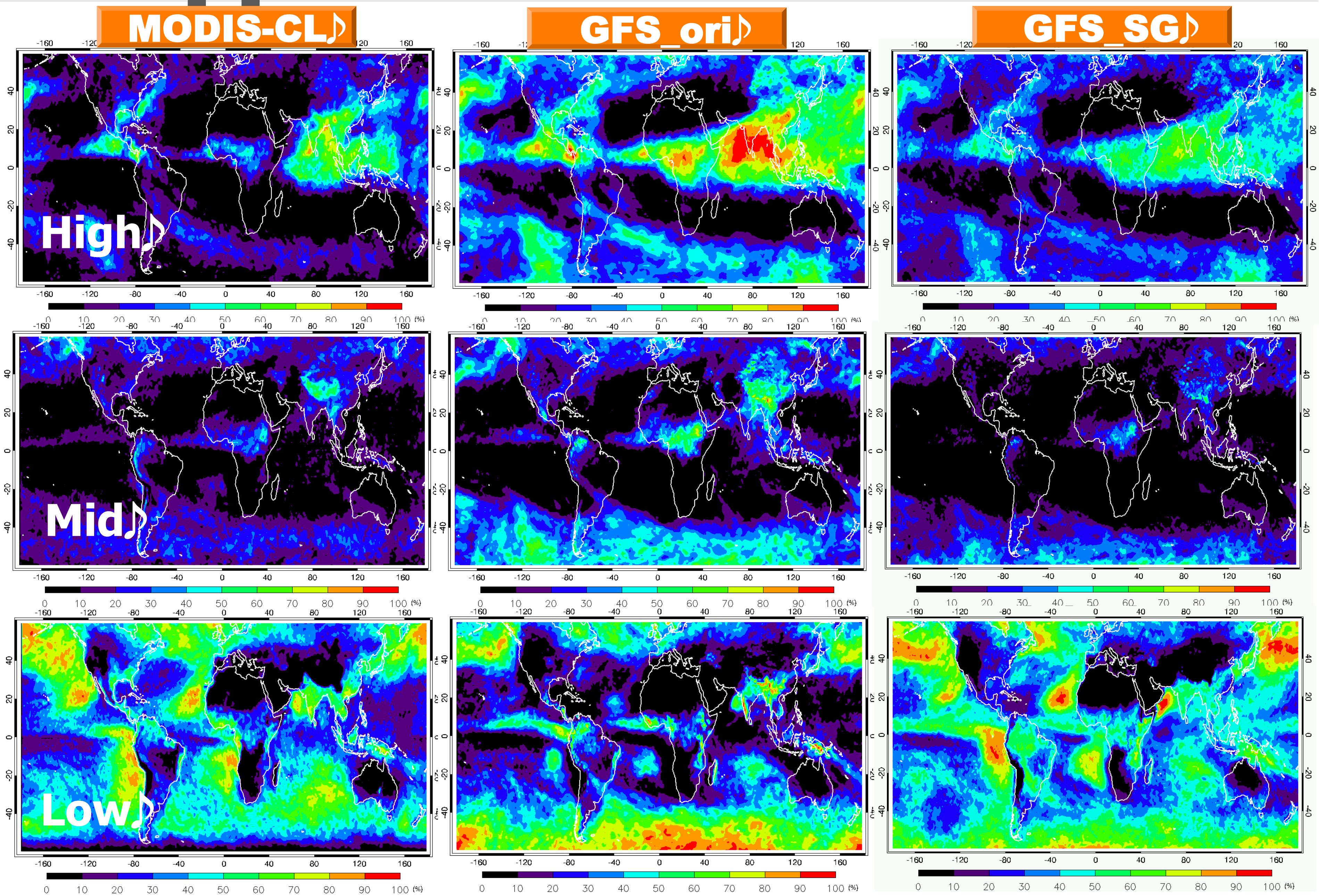
Bias = AERI measurements – AIRS or GFS

Application

Other cloud scheme

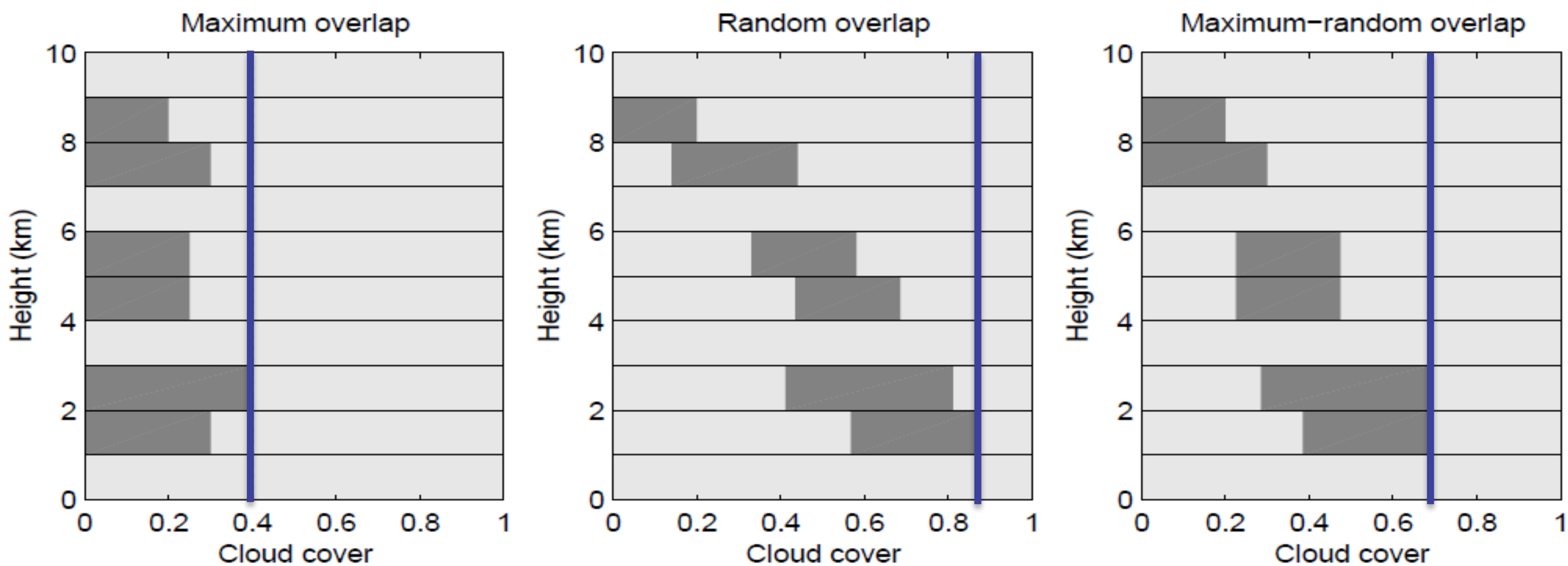
GFS scheme		SG scheme
Xu and Randall (1996)	Based	Slingo (1987) Gordon (1992)
An equation is from empirical formula	Similar	Many of constants are based on observations
Only one equation determines CFR	Differ	Several equations determine CFR
T, RH, and Cloud mixing ratio	Variables	RH, convective cfr, vertical velo, lapse rate
Maximum-Random overlap	Overlap	Maximum overlap

Application : cloud fraction - July



Cloud Overlapping Scheme

Overlap assumption



A schematic illustrating the three overlap assumptions (from Hogan and Illingworth, 2000)

Geleyn and Hollingsworth 1979

Random overlap: noncontiguous layers, Maximum overlap: contiguous layers
Most widely used cloud overlap approximation in modern GCMs♪

C_{max} = Max(C1, C2)

C_{ran} = C1+C2-C1*C2

Cloud Overlapping Scheme

Previous studies

$$C_{true} = a*C_{max} + (1-a)*C_{ran}, \text{where } a(\Delta z) = \exp(-\Delta z/L_{cf})$$

EXPONENTIAL RANDOM

▶ Hogan and Illingworth

2000

▶ For vertically continuous cloud, the degree of correlation between the cloud positions decreased with vertical separation of the layers

Lcf : 4 km♪

▶ Mace and Benson-Troth

2002

▶ Using MMCR Radar data from 4 ARM sites :SGP, TWP, Manus, Nauru

Lcf : 3.9 km at SGP, 4 km at Manus, 4.6 km at Nauru

▶ Pincus et al.

2005

▶ Using CRM simulation, Stratiform and convective clouds have different overlap.

St: Random, Con: Max

▶ Naud et al.

2008

▶ Using cloud radar data from ARM with NCEP reanalysis data

Lcf : 2 km at SGP, 2.3 km at Manus, 1.8 km at Nauru

▶ Barker

2008

▶ Using CloudSat and CALIPSO data

Lcf : median value of 2 km for global scales

▶ Shonk et al.

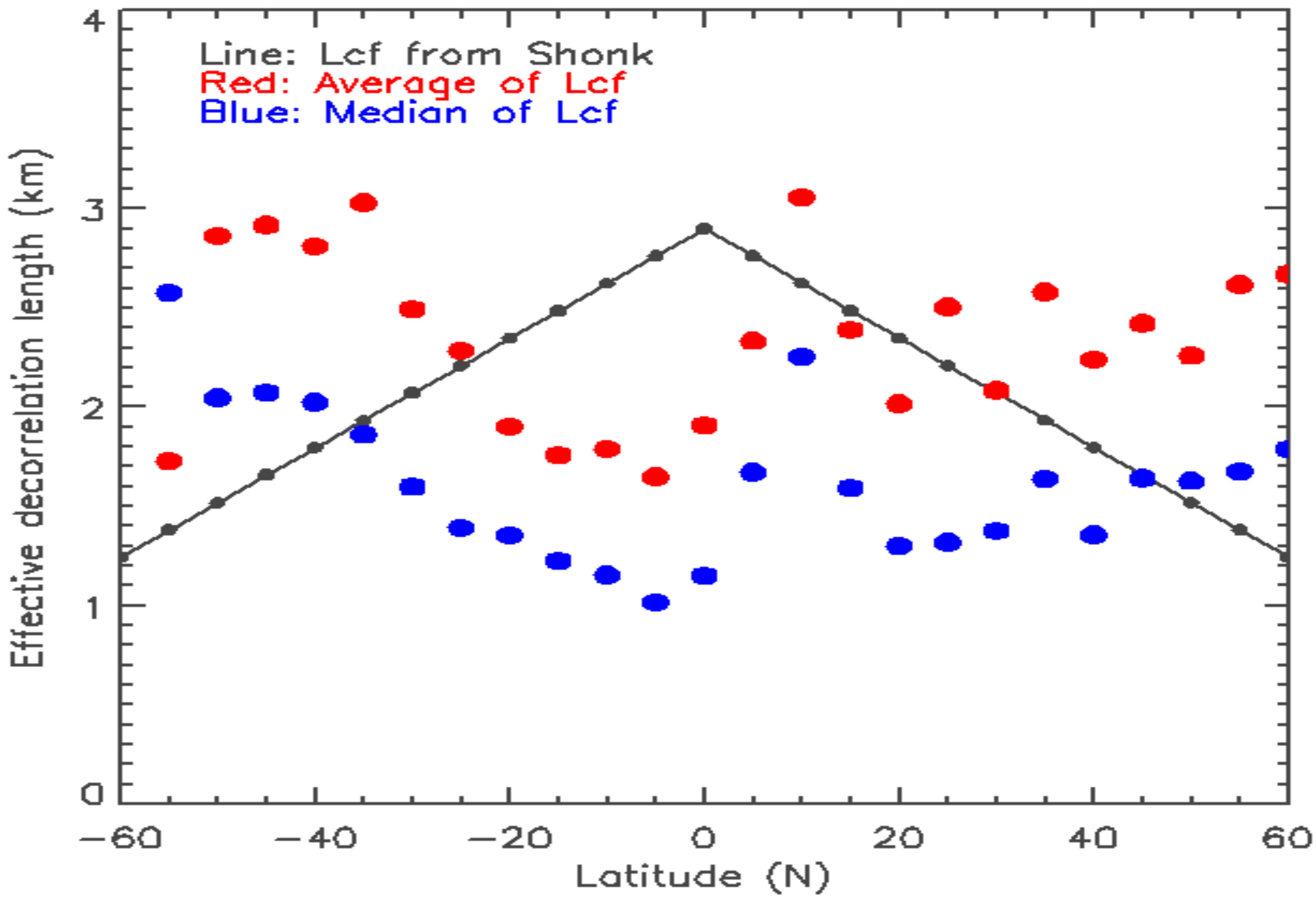
2010

▶ Based on two studies, they suggest a simple linear fit

Lcf : dependent on only latitudes

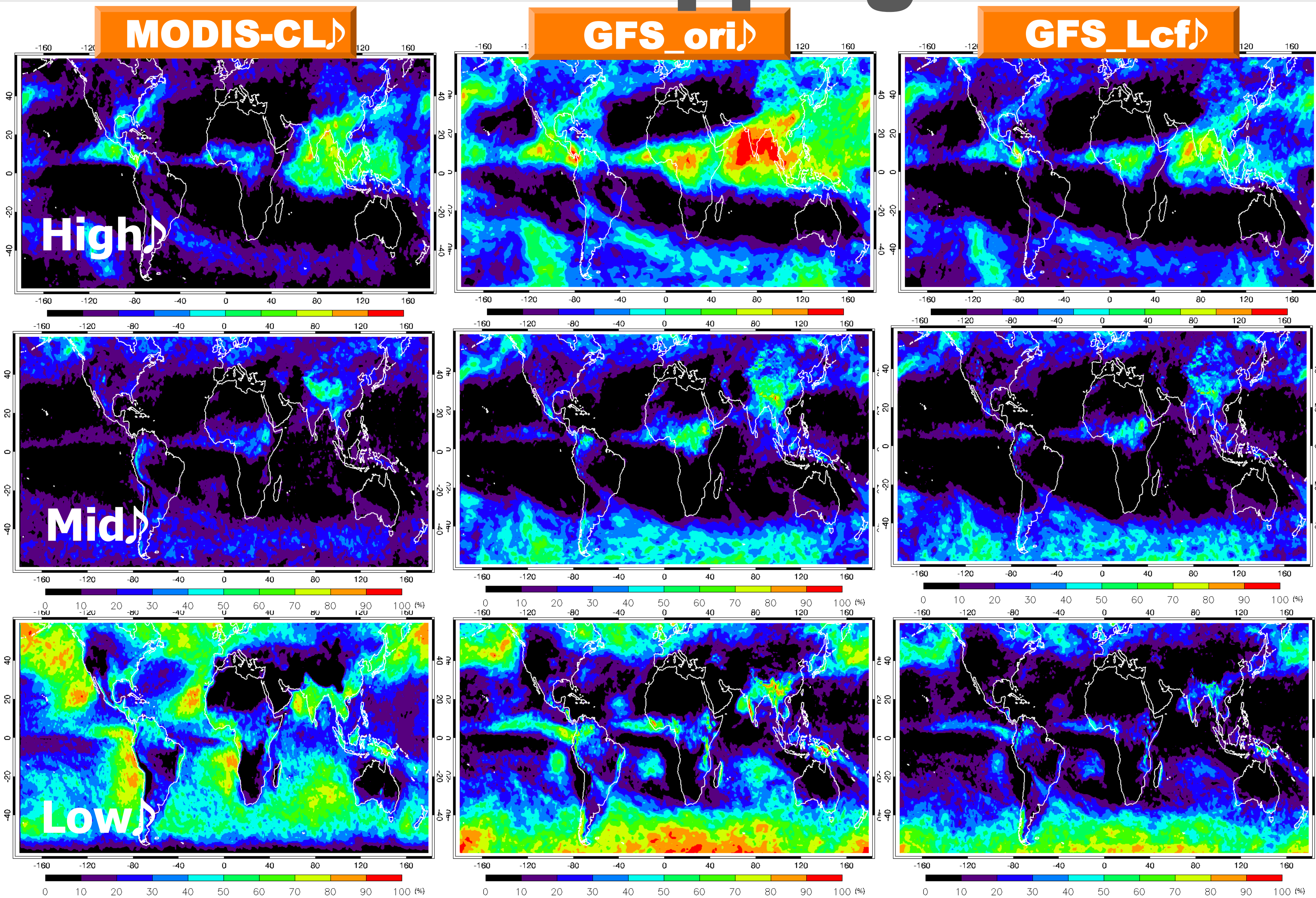
Cloud Overlapping Scheme

Comparisons of Lcf

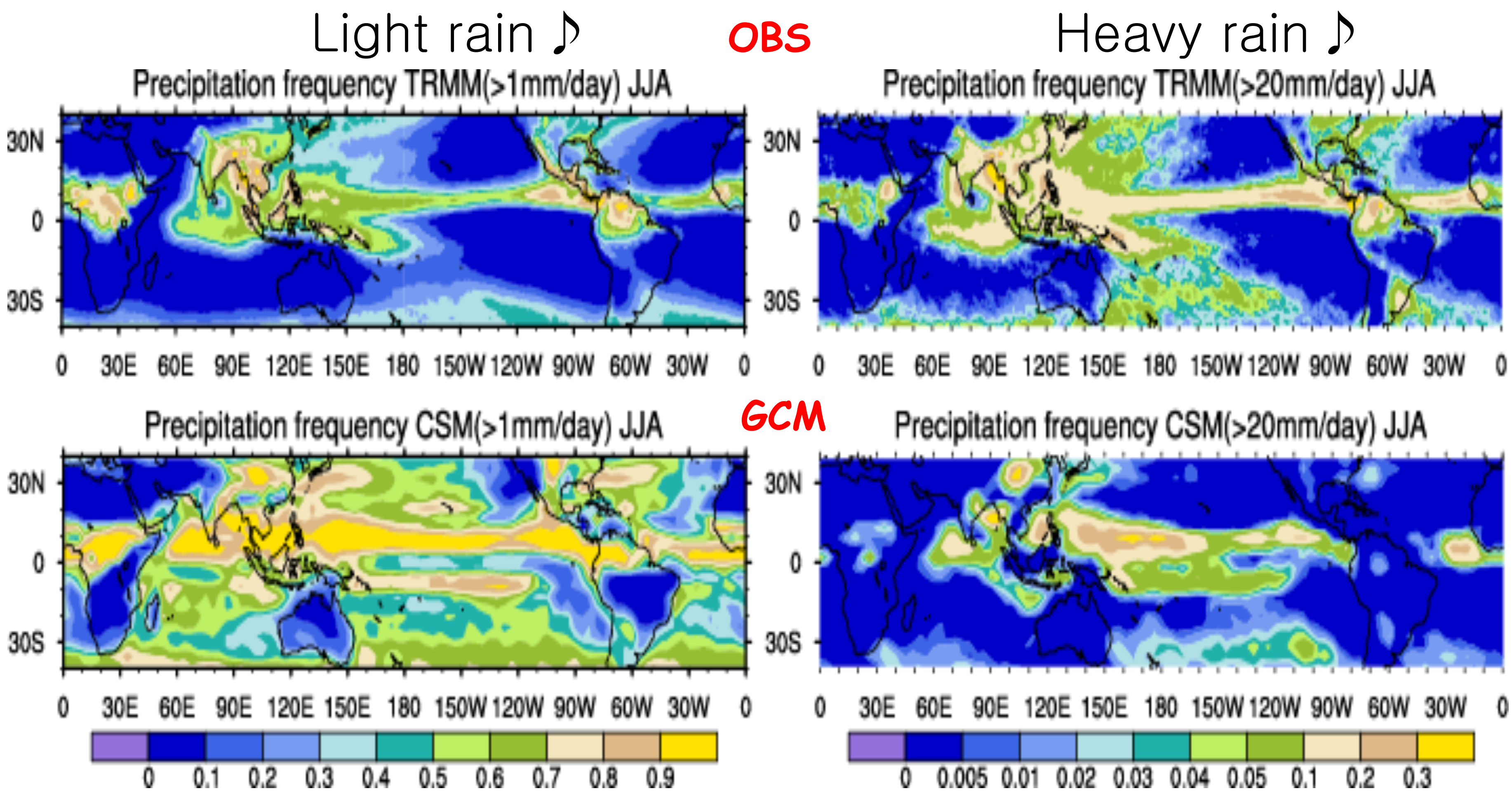


Lcf values as a function of latitude for July 2007. The black solid line is a simple linear fit suggested by Shonk et al. (2010) and the red and blue dots show mean and median values of Lcf, respectively.♪

Cloud Overlapping Scheme



What is the systematic model biase in Precipitation Simulation?



JJA (June, July and August) daily precipitation frequency (%)
(>1 mm day^{-1}, left; >20 mm day^{-1}, right)

Wu et al. (2007, GRL)

nature geoscience

ARTICLES

PUBLISHED ONLINE: 13 NOVEMBER 2011 | DOI: 10.1038/NGEO1313

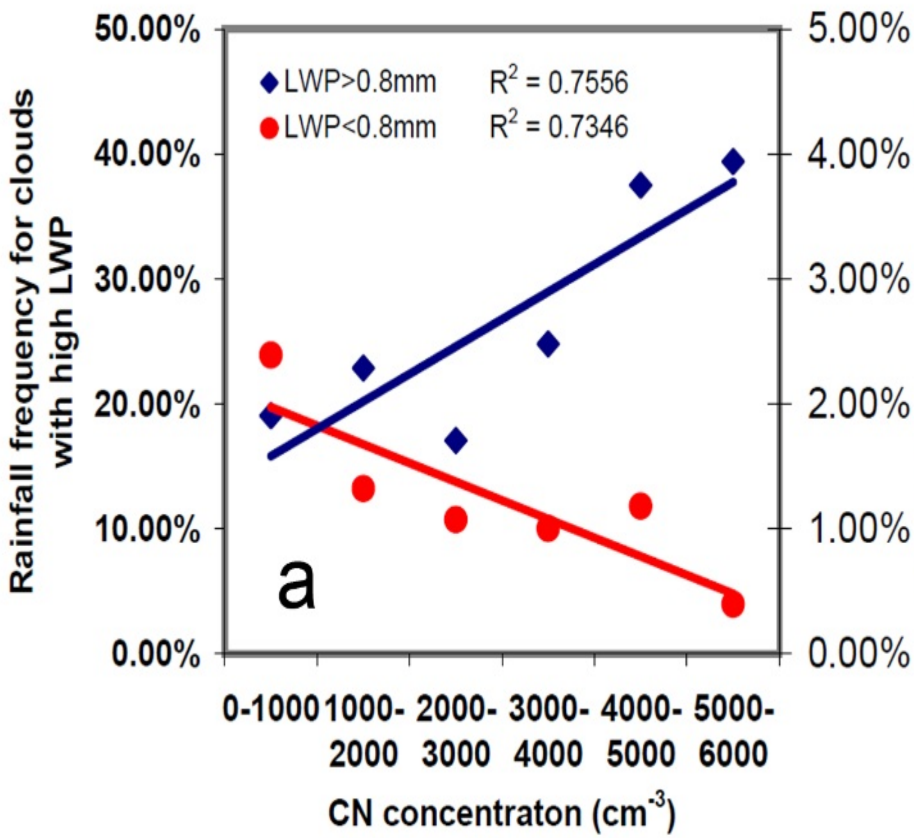
Long-term impacts of aerosols on the vertical development of clouds and precipitation

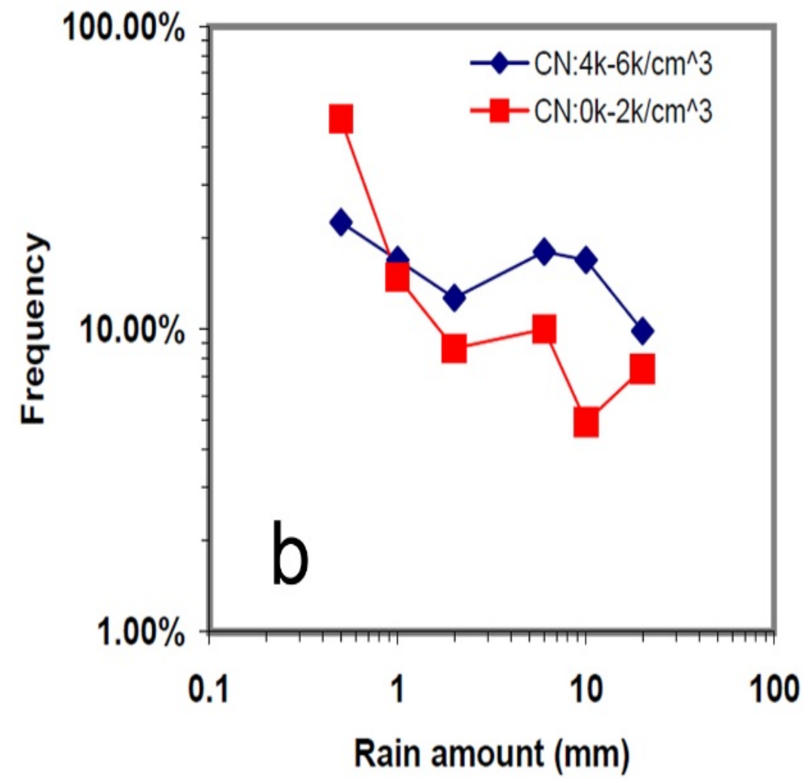
Zhanqing Li[1,2,3]★, Feng Niu[3], Jiwen Fan[4], Yangang Liu[5], Daniel Rosenfeld[6] and Yanni Ding[3]

Aerosols alter cloud density and the radiative balance of the atmosphere. This leads to changes in cloud microphysics and atmospheric stability, which can either suppress or foster the development of clouds and precipitation. The net effect is largely unknown, but depends on meteorological conditions and aerosol properties. Here, we examine the long-term impact of aerosols on the vertical development of clouds and rainfall frequencies, using a 10-year dataset of aerosol, cloud and meteorological variables collected in the Southern Great Plains in the United States. We show that cloud-top height and thickness increase with aerosol concentration measured near the ground in mixed-phase clouds—which contain both liquid water and ice—that have a warm, low base. We attribute the effect, which is most significant in summer, to an aerosol-induced invigoration of upward winds. In contrast, we find no change in cloud-top height and precipitation with aerosol concentration in clouds with no ice or cool bases. We further show that precipitation frequency and rain rate are altered by aerosols. Rain increases with aerosol concentration in deep clouds that have a high liquid-water content, but declines in clouds that have a low liquid-water content. Simulations using a cloud-resolving model confirm these observations. Our findings provide unprecedented insights of the long-term net impacts of aerosols on clouds and precipitation.

Aerosol effect

Effects of Aerosols on Rainfall Frequency & Rain Rate





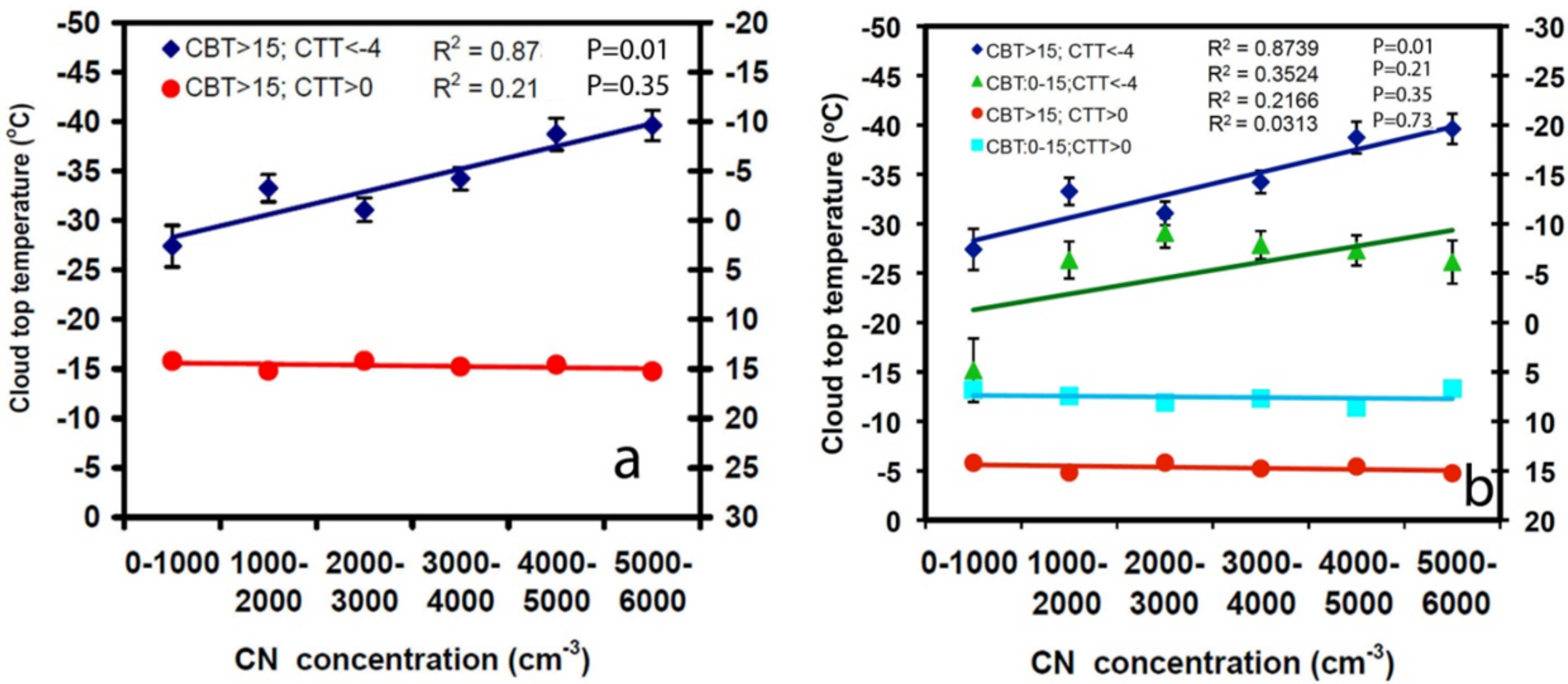
Results♪

1. For thin clouds, rainfall occurrence is suppressed by aerosols (30%)
2. For thick clouds, rainfall frequency is increased by aerosols (50%)
3. Light rain is suppressed by aerosols, heavy rain is enhanced.

Li et al. (2011, Nature-Geosci)

Aerosol effect

Impact of Aerosols on Cloud Phase & Height

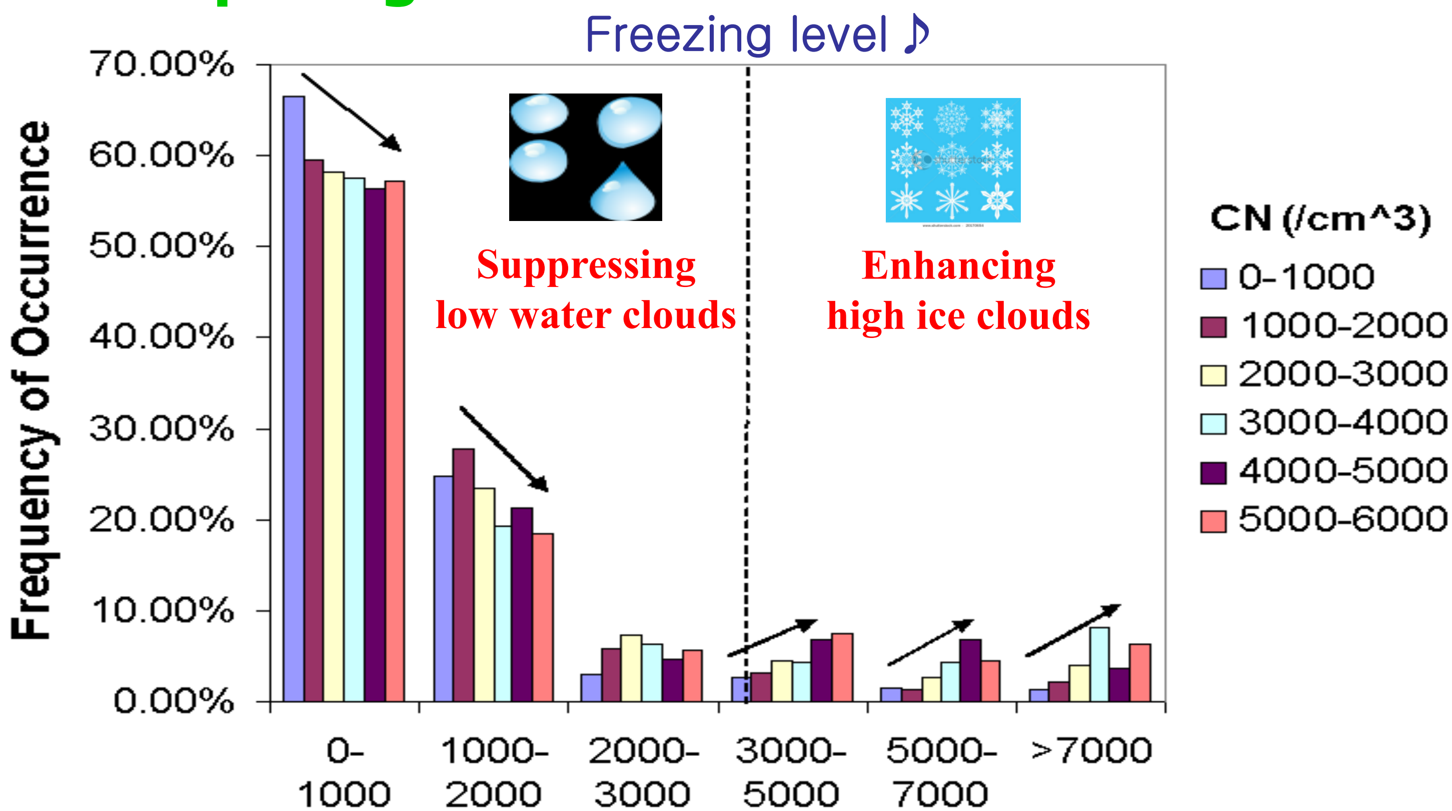


Results♪

1. For mixed-phase clouds of low cloud base, cloud top (also thickness) increases systematically with aerosol number concentration
2. For warm clouds, cloud top height (thickness) is not affected.

Aerosol effect

Effects of Cloud Phase Frequency of Occurrence of Cloud Top Height



Results♪

1. As CN increases, high clouds occurred more frequently but low clouds occurred less frequently

Summary

Findings

Diagnosis of clouds

- The GFS model captures well the spatial distributions of hydrometeors compared to satellite retrievals, although large differences exist in the magnitudes.
- The GFS model generates more high and mid-level clouds, but less low-level clouds than do satellite retrievals and tends to miss low-level marine stratocumulus clouds.
- An underestimation of low clouds leads to more outgoing LW radiation and less SW radiation at the TOA.
- The GFS temperature field agrees well with observations, the GFS RH simulations both in the lower and upper troposphere tend to be overestimated than observations.

Aerosol on rain

- For thin clouds, rainfall occurrence is sup pressed by aerosols (30%)
- For thick clouds, rainfall frequency is incr eased by aerosols (50%)

Aerosol on cloud height

- For mixed-phase clouds of low cloud base , cloud top (also thickness) increases with aerosol number concentration
- For warm clouds, cloud top height (thickn ess) is not affected.

Aerosol on cloud phase

- As CN increases, high clouds occurred m ore frequently, but low clouds occurred le ss frequently.